Measurements of Upper Tropospheric Humidity at Low Temperatures during CRYSTAL-FACE

Robert Herman, Andrew Heymsfield,

Brian Ridley, Paul Bui, Bill Engblom

CRYSTAL-FACE Science Team Meeting

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R. F. Troy, J. A. Herman, B. Finamore, W. S. Woodward

E. M. Weinstock, R.-S. Gao, C. R. Webster, L. Avallone

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Outline

1) Introduction

2) Science: Humidity in Contrails

3) Accuracy Issues

4) Ongoing Work

Motivation

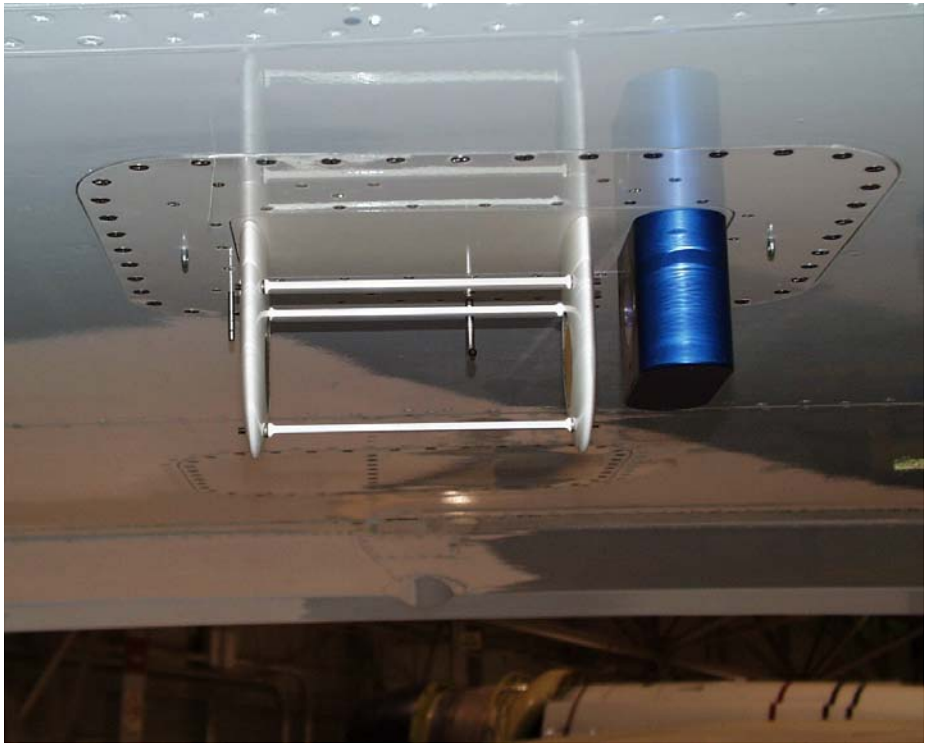
- Water dominates the tropospheric energy cycle, but is associated with large uncertainties in climate prediction.
- Water vapor is a key meteorological variable (along with p, T, w, CCN) to determine when and where clouds form.
- Ice nucleation mechanisms are constrained by measurements of relative humidity with respect to liquid water (RH) and with respect to ice (RHI).
- Laser hygrometers provide fast, precise measurements of water vapor.

JPL Laser Hygrometer (JLH) on the WB-57

Measurement: water vapor (*in situ*).

Technique:
- Near-infrared absorption spectroscopy.
- Scan spectrum by tunable diode laser.
- **New line: 7306.7 cm^{-1} (1368.6 nm).**
- Detection by wavelength-modulation.

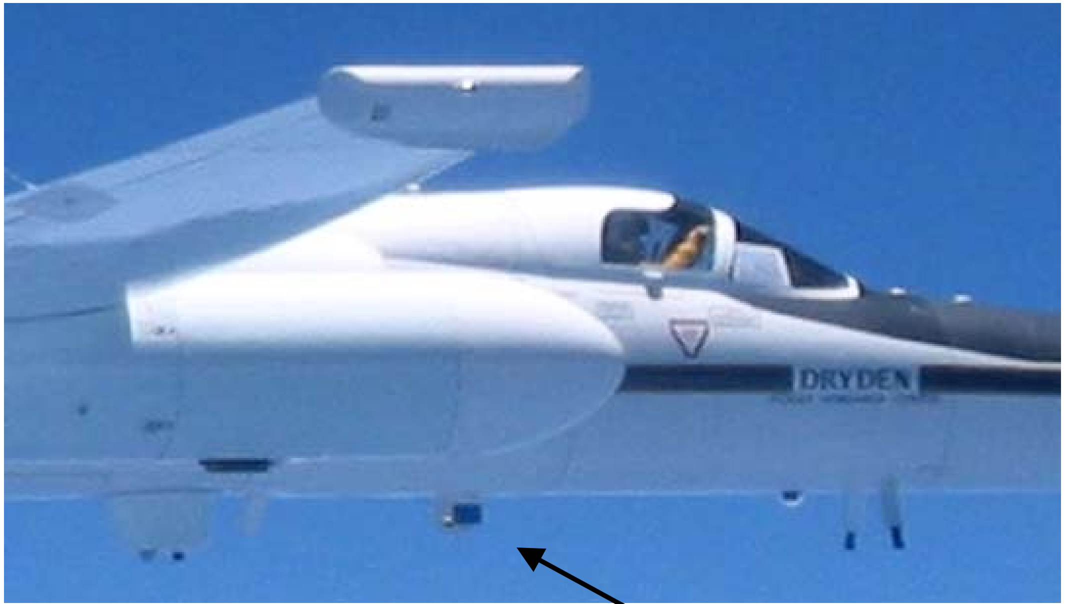
Configuration:
- Optical cell external to aircraft (right).
- Open-path Herriott multi-pass cell.
- 11.13-m path folded between 2 mirrors.



Specifications:
- Detection range: 0.1 to 1000 ppmv
- Accuracy: 10%
- Precision: 0.05 ppmv H_2O (10-sec)
- Time-resolution: 1.3 sec
- Mass: 20 lbs.
- Power: 100 W (maximum)
- Voltage: 28 V DC

Mounting:
- Underwing hatch on WB-57 right wing.
- Blue housing contains laser and detector.
- White structure holds mirrors in place.

JPL Laser Hygrometer (JLH) on the ER-2



Technique:
- Same as WB-57 JLH.
- **New spectral line: 7306.7 cm^{-1} (1368.6 nm).**

Mounting:
- Pressurized lower Q-bay of the ER-2 (new hardware, cables).
- 2-inch spacers added for CRYSTAL-FACE.

Status:
- Laser had to be replaced in the field.
- Flight data will be reprocessed with a new algorithm.

Deliverables to CRYSTAL-FACE

JLH archived JW files (utilizing P, T from MMS and P/T):

- Water vapor volume mixing ratio (ppmv),
- Frostpoint temperature (K),
- Water partial pressure (hPa),
- Saturation vapor pressure wrt liquid, esh (hPa),
- Saturation vapor pressure wrt ice, esi (hPa),
- Relative Humidity wrt ice, RHI (%),
- Specific Humidity (g per kg air).

Archived flights:

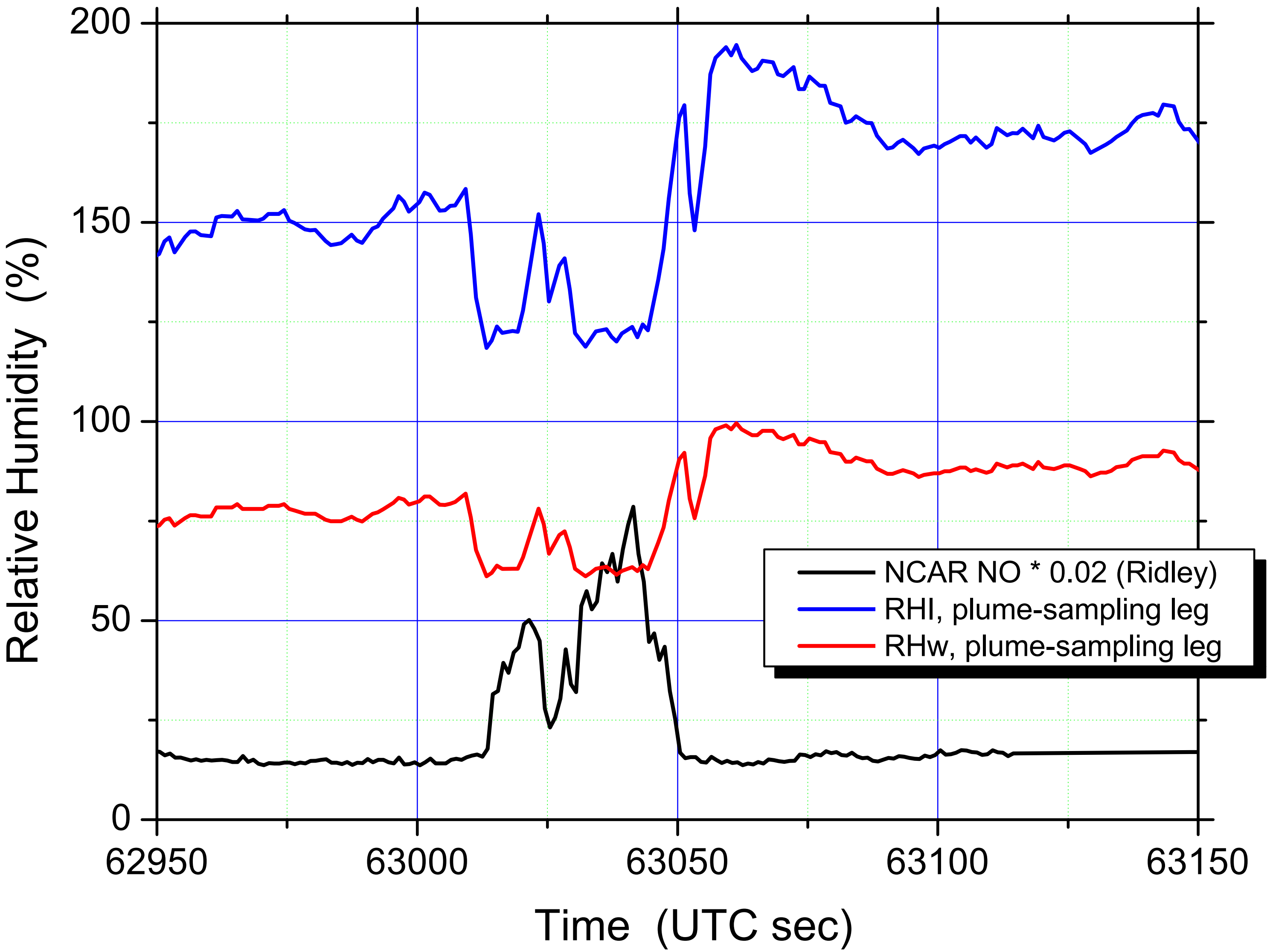
- WB-57F: Feb. 2003 revised data for 13 flights.
- ER-2: 5 prelim. files. Revised files TBD for 9 science flights.

Science Issues:

- ***Contrails***
- Clear-Air Supersaturation
- Humidity in Cirrus Clouds
- Microphysics
- ER-2: distribution and transport of stratospheric H_2O.

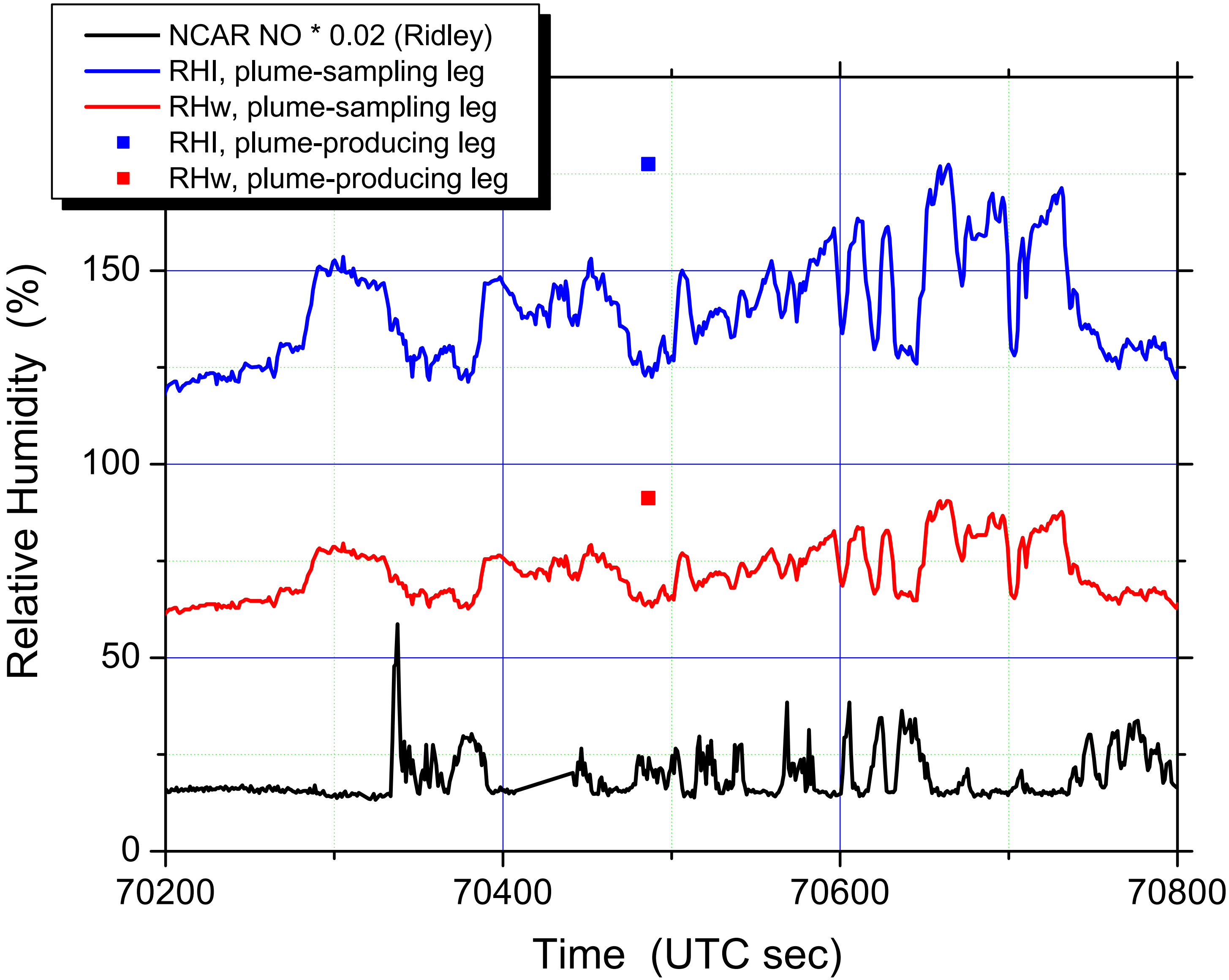
Relative humidity in contrails

20020713: ER-2 contrail sampled by WB-57F



Relative humidity in contrails

20020713: WB-57F contrail sampled by WB-57F



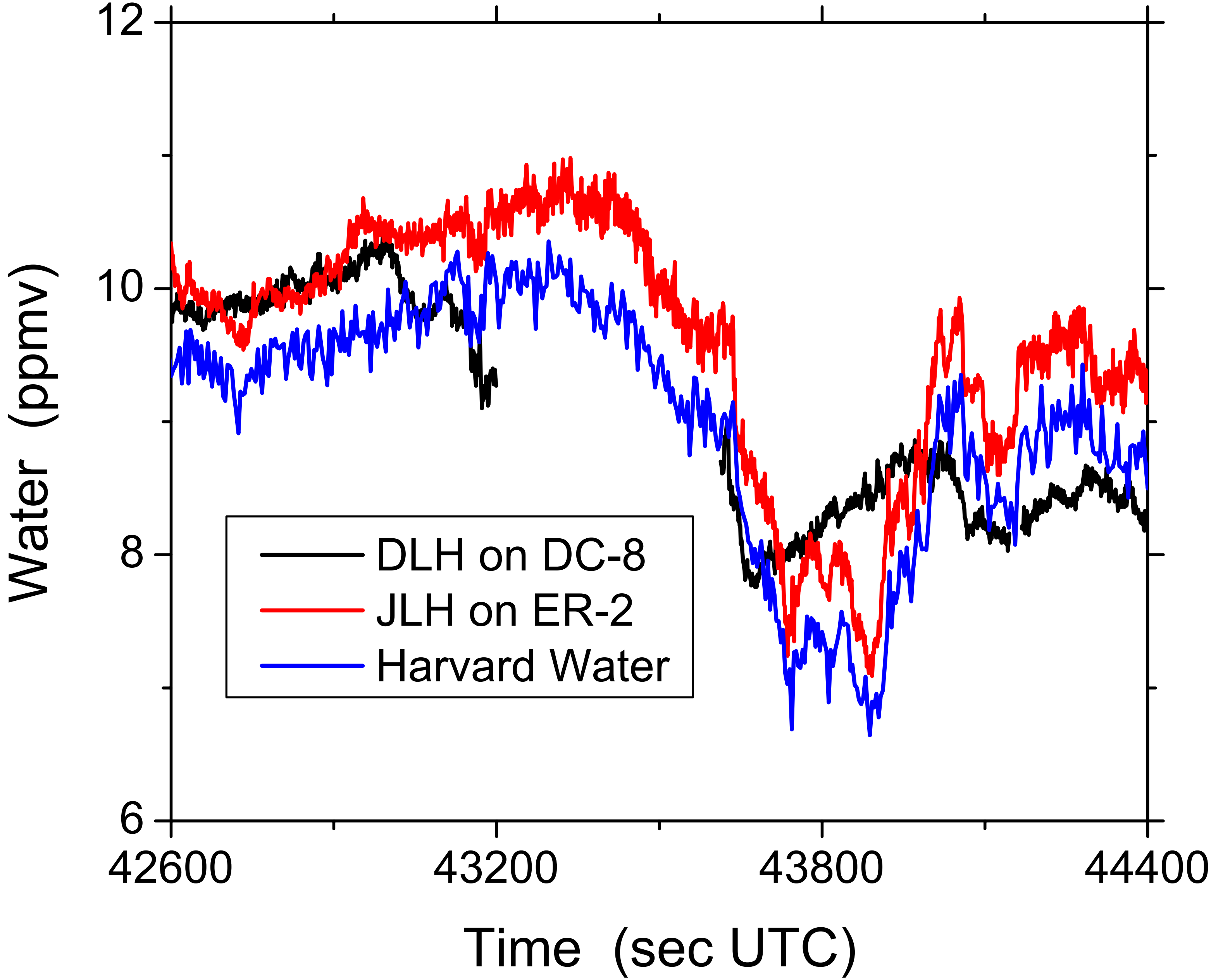
Relative humidity in contrails

Nucleation:
Exhaust particles are activated and heterogeneously nucleate ice.

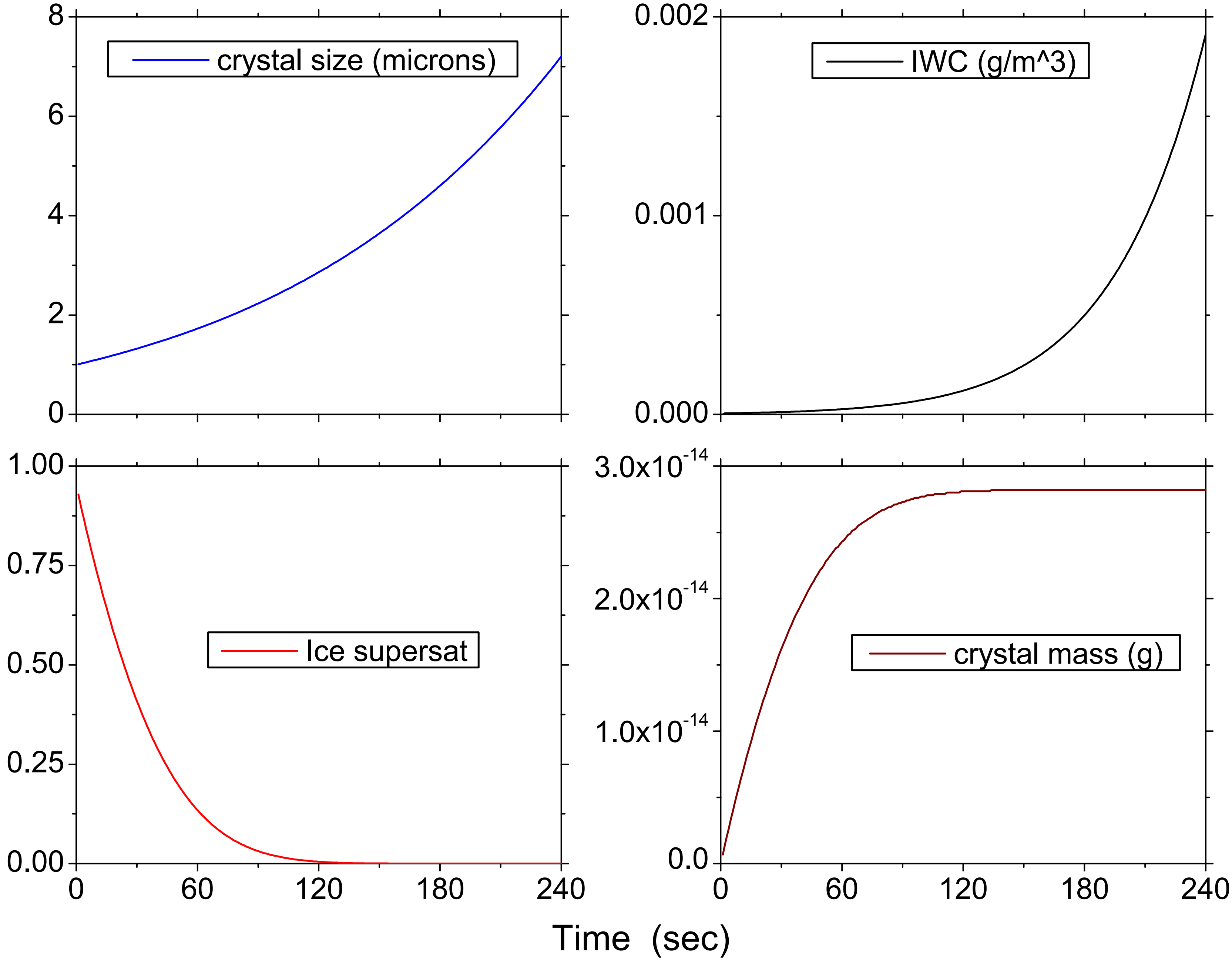
Growth of ice crystals:
- Persistent contrails require RHI>100% to drive growth (Gierens, 1996; Jensen et al., 1998; Heymsfield et al., 1998).
- Large concentration of growing ice crystals pulls RHI down to 100% (Jensen et al., 1998; Heymsfield et al., 1998).

Previous visible contrail measurements:
- Schröder et al. (2000) – large range of RH measured by cryogenic mirror.
- Heymsfield et al. (1998) – DLH measurements in SUCCESS indicate RHI=100% in contrail cores (-52°C).

SOLVE: 23 Jan 2000 intercomparison



Contrail Model

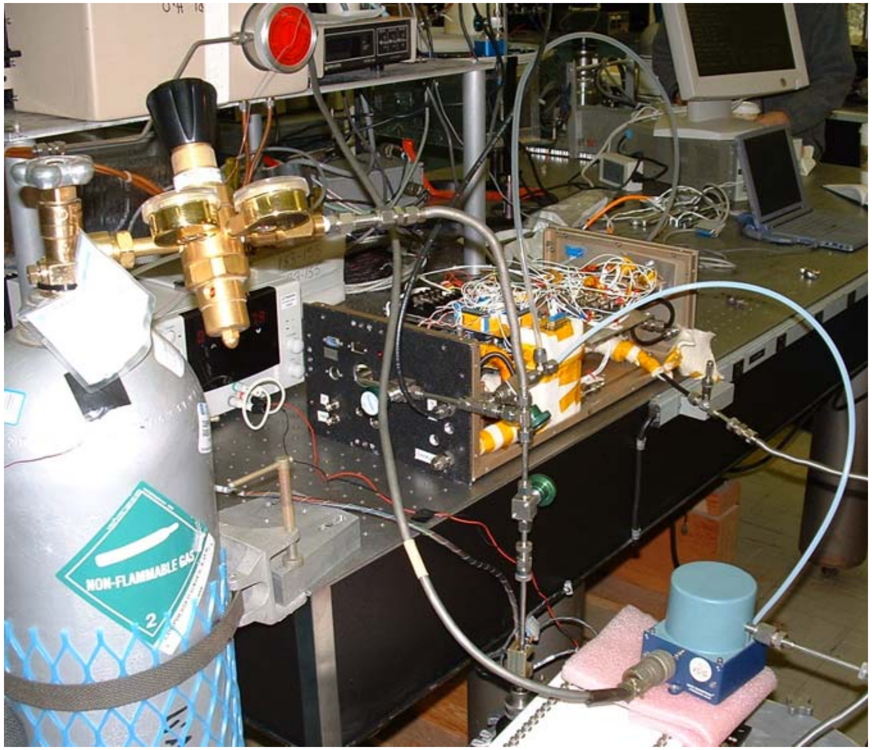


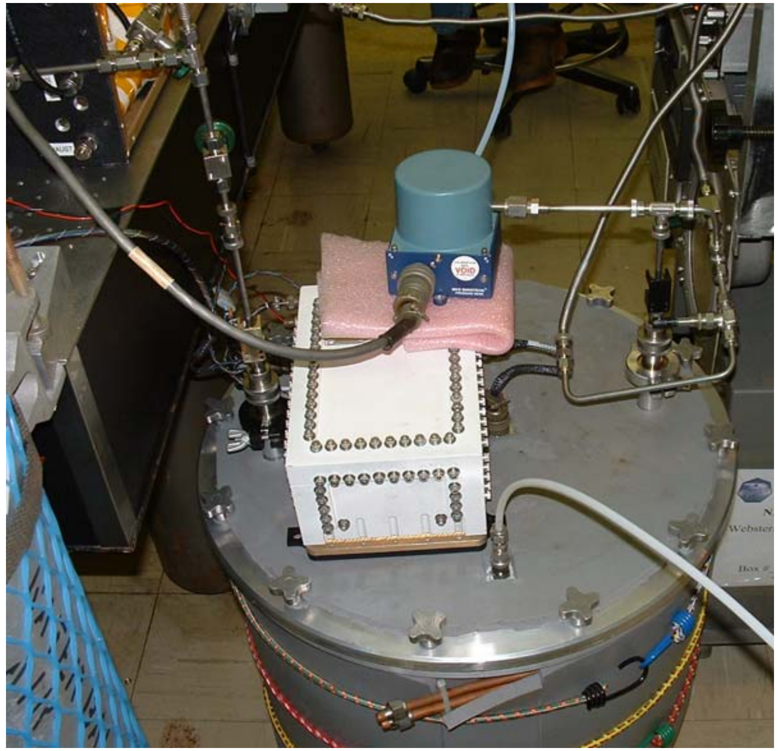
Accuracy Issues

- Temperature: ±0.5°C or ±8% RH,
- Pressure,
- Variation of flow with aircraft Mach number, pitch angle,
- Particle evaporation due to ram heating upstream of wing,
- Background near-infrared radiation,
- Saturation vapor pressure,
- Laboratory Baratron: ±0.4%,
- Leaks in laboratory systems,
- Pressure- and concentration-dependence of correction curve,
- Cylinder composition: ±0.2°C or ±2.5% RH,
- Laser properties,
- Spectral parameters.

Calibration

Cross-calibration at JPL with:
Colorado Laser Hygrometer (CLH): L. Avallone (P.I.)





Water sources:
- Licor dewpoint generator,
- air cylinder with 41.6 ppmv water.

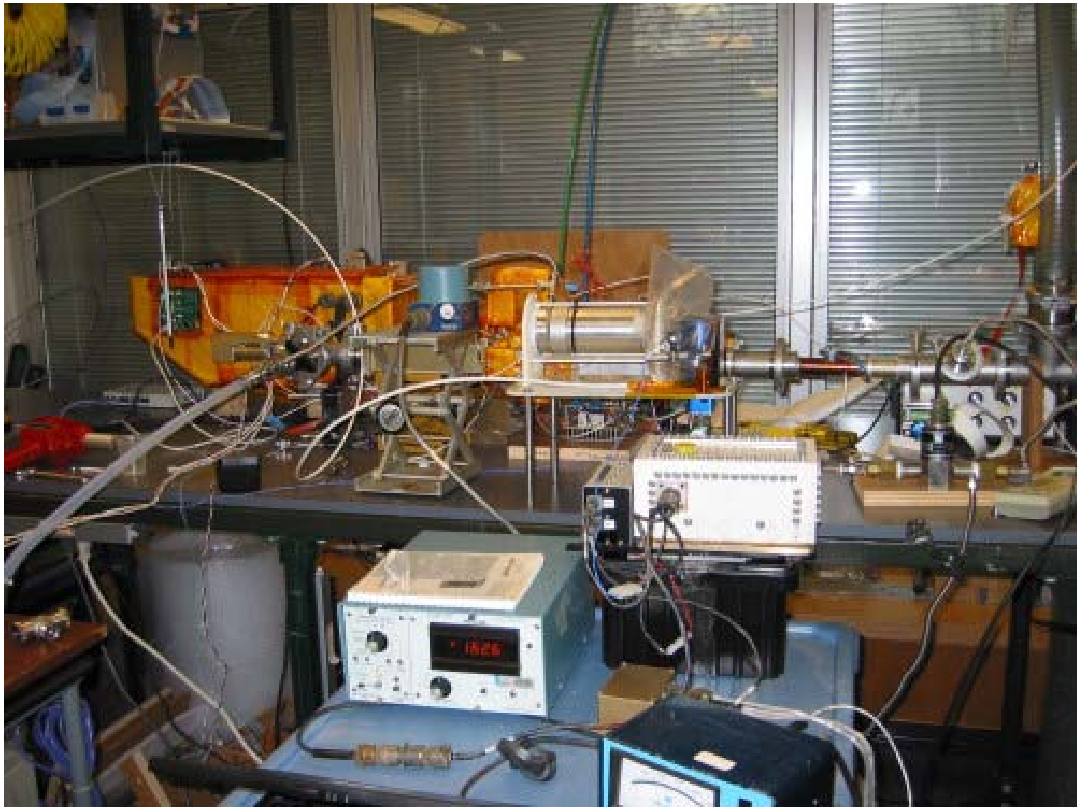
Calibration: part 2

Cross-calibration at Harvard University
(see posters by E. M. Weinstock and R. L. Herman)

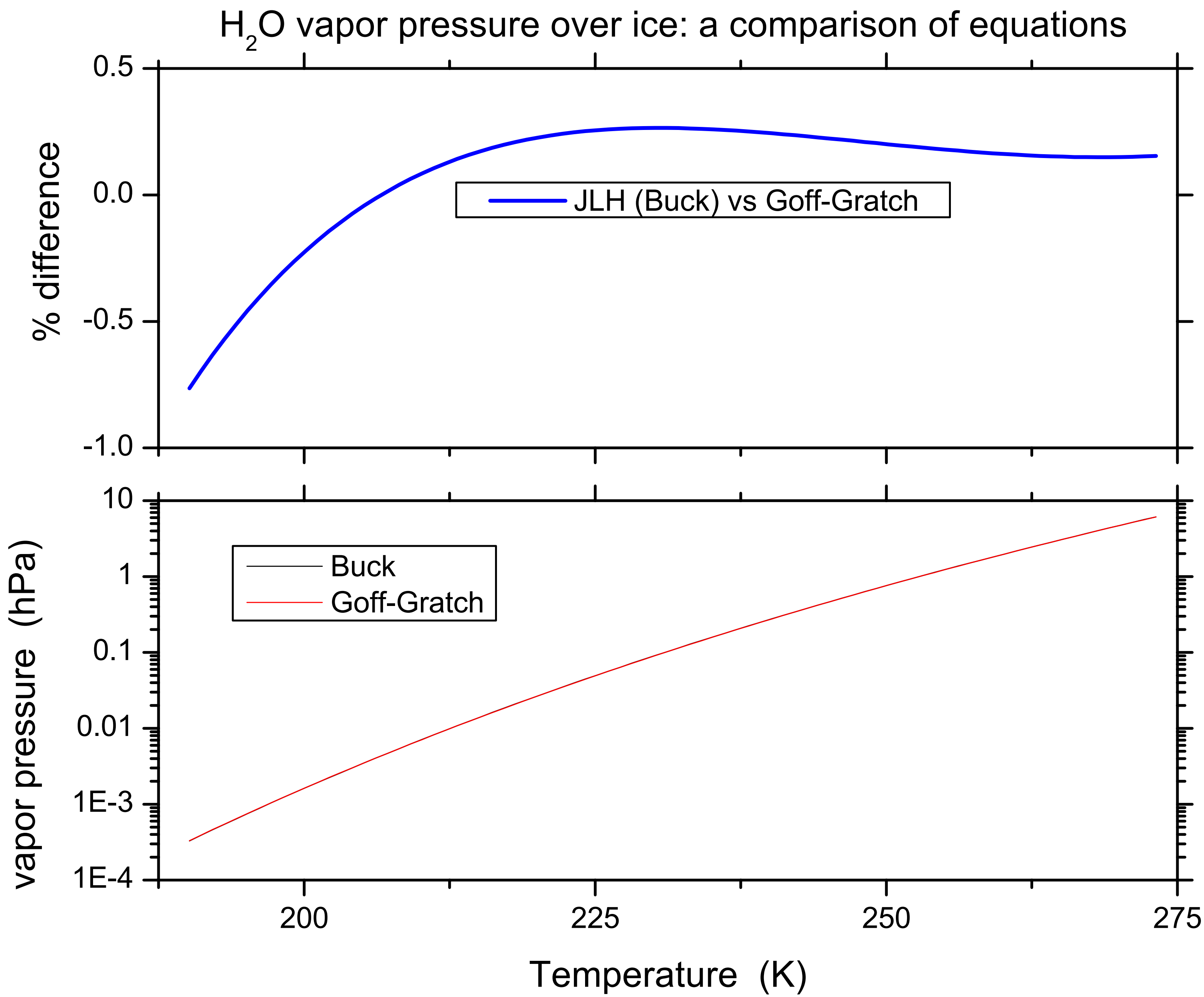
Water source:
Bubbler + dry air

Reference standards:
• UV absorption
• Chilled-mirror hygrometer

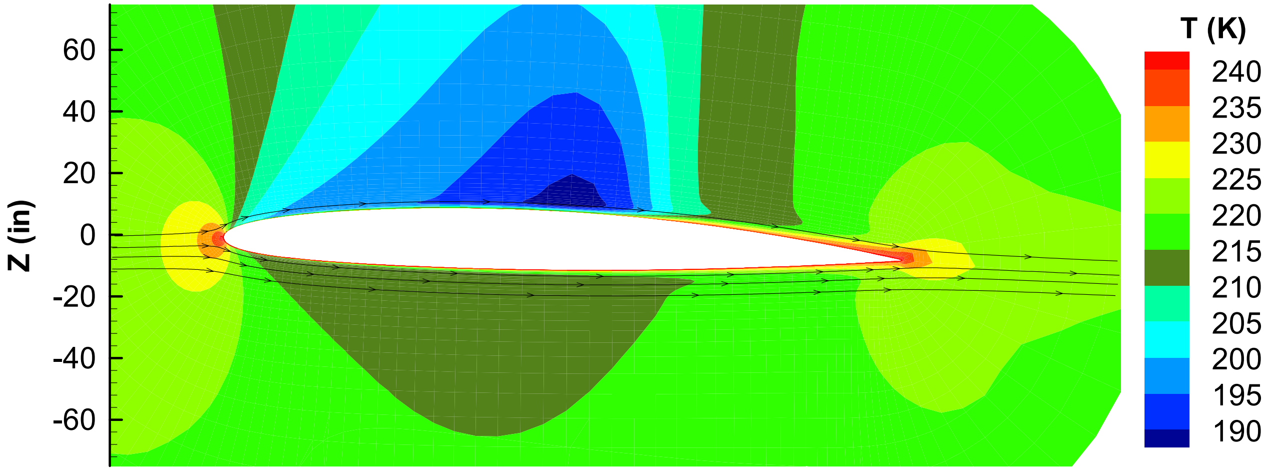
The revised JLH data is based on this calibration.



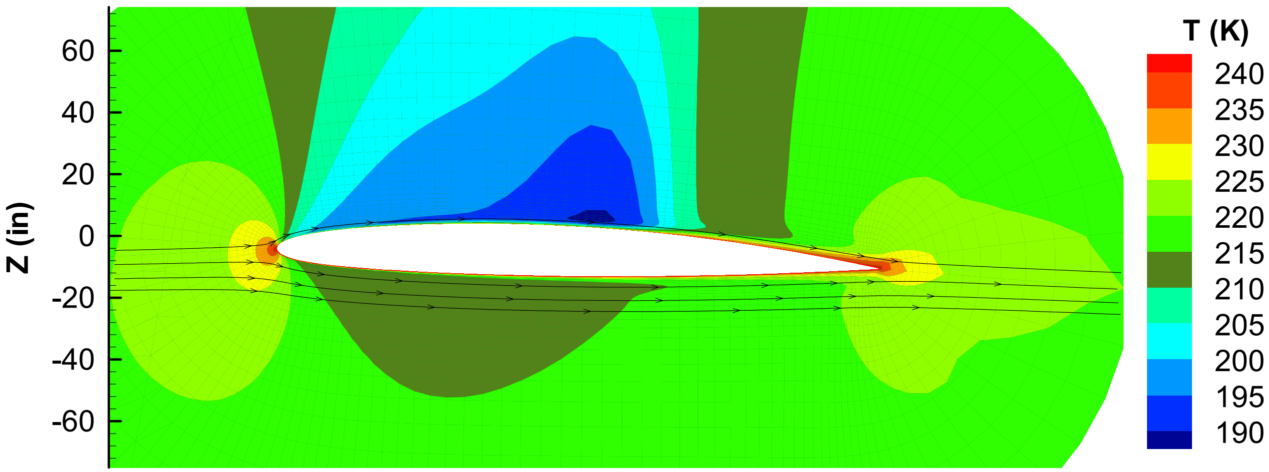
Water Vapor Pressure



TEMPERATURE CONTOUR SLICE
(WB-57, Mach = 0.8, Alt = 50 kft)



approx. 40% root-to-tip



approx. 53% root-to-tip

W. A. Engblom
Fluid Mechanics Department
Vehicle Systems Division

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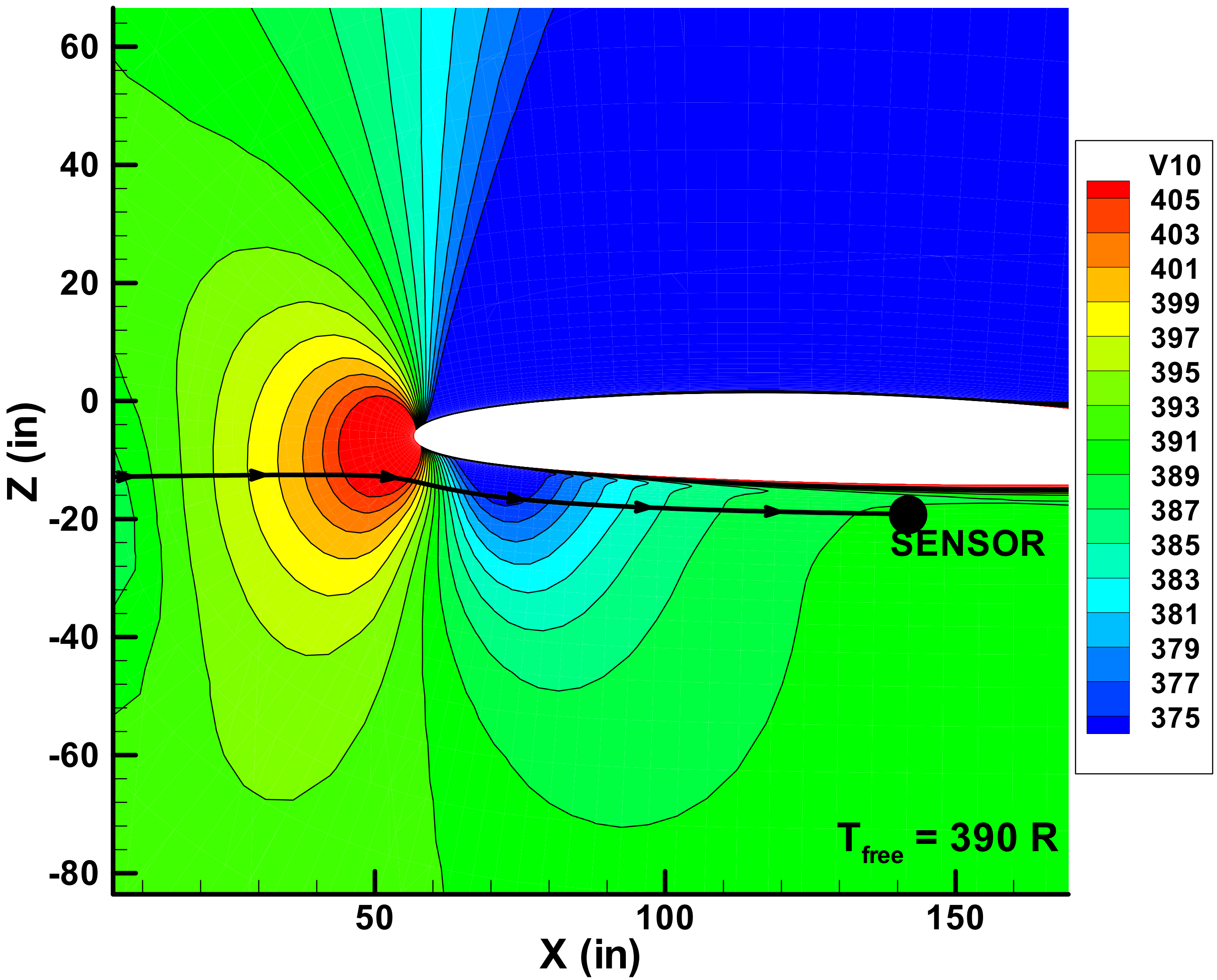
TEMPERATURE CONTOUR SLICE at STA 460
(WB-57, Mach = 0.80, Alt = 50 kft, α = 0 deg)



W. A. Engblom
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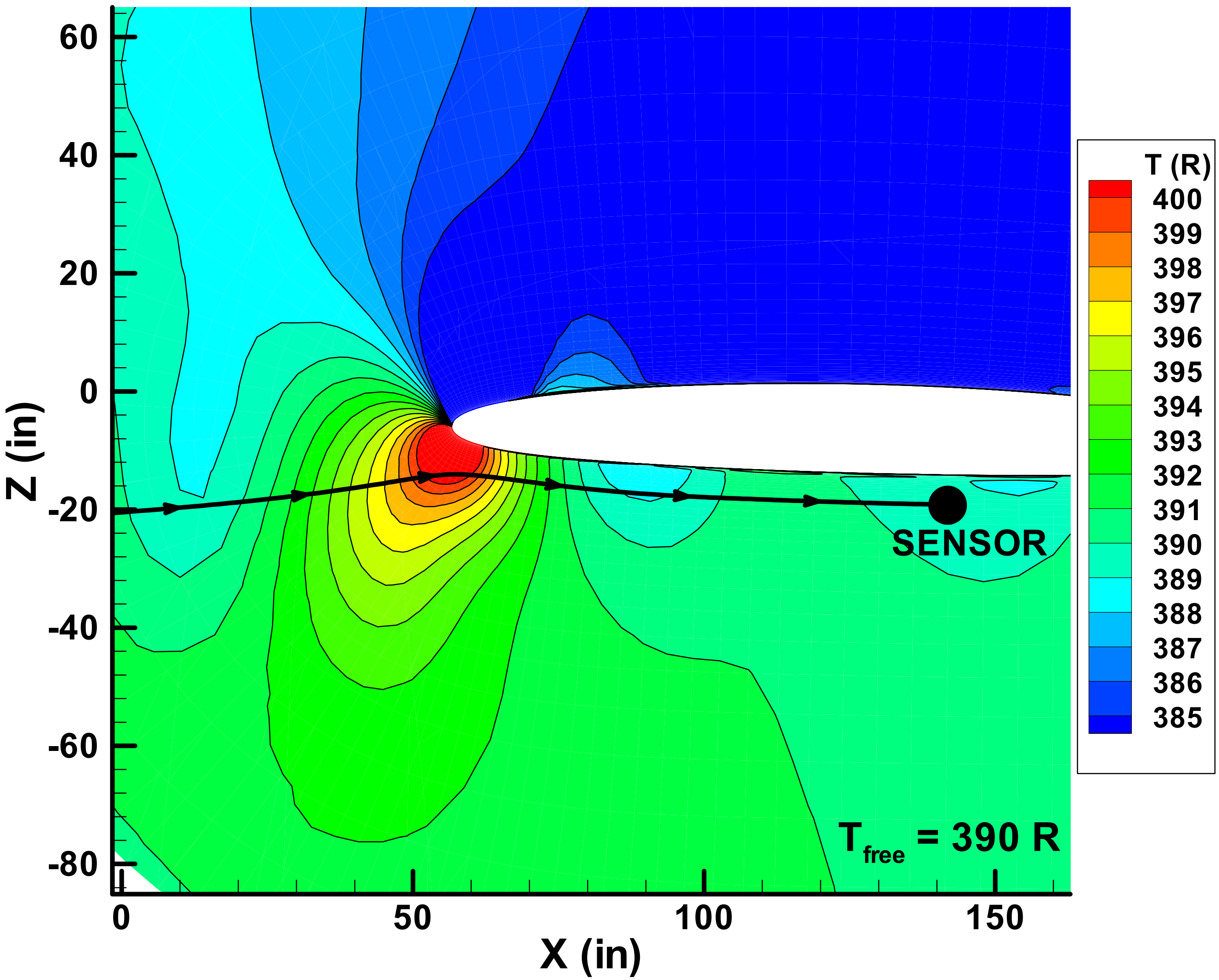
TEMPERATURE CONTOUR SLICE at STA 460
(WB-57, Mach = 0.54, Alt = 65 kft, α = 2 deg)



W. A. Engblom
Fluid Mechanics Department
Vehicle Systems Division

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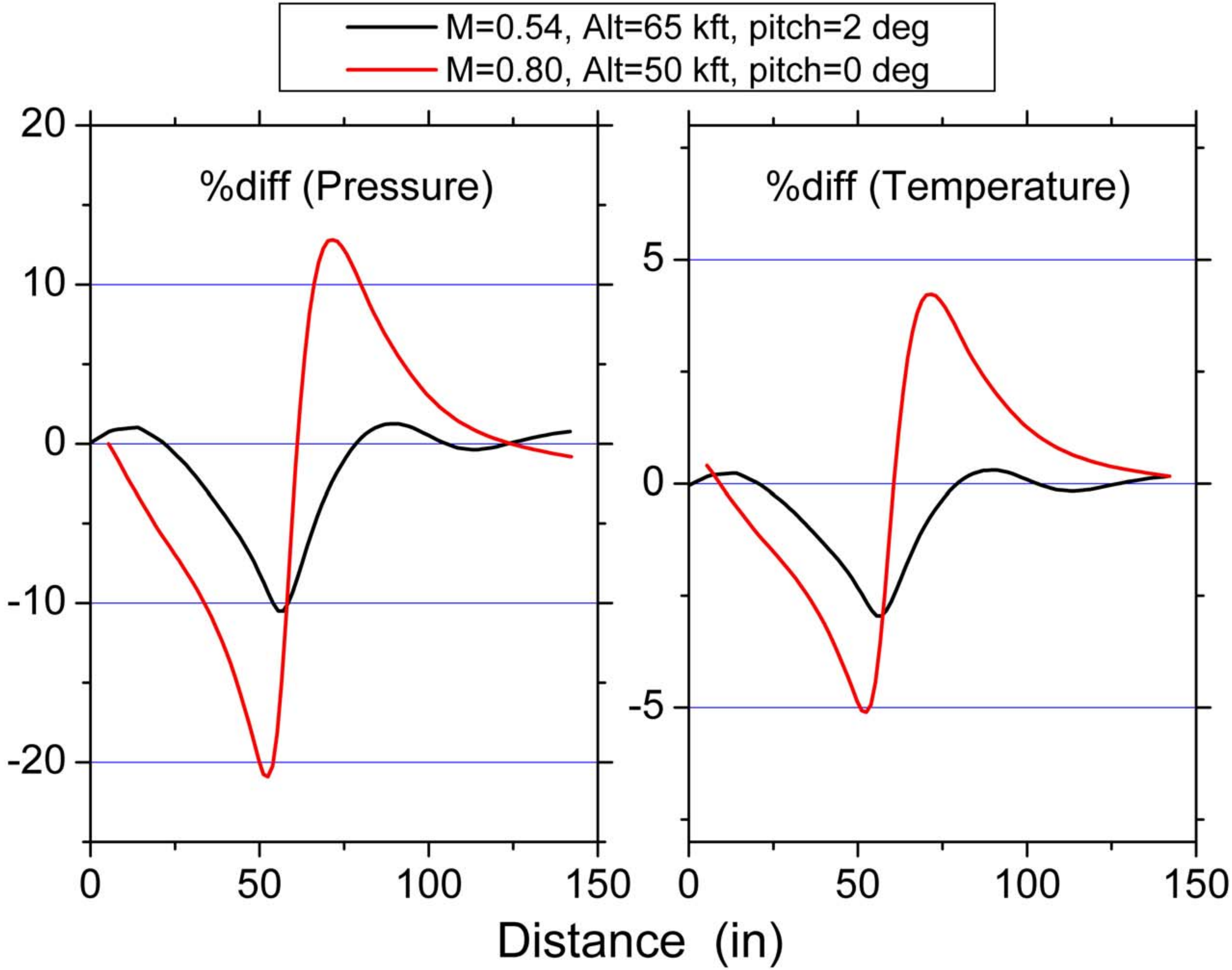
Trajectories (Bill Engblom)



Ongoing Work

Laboratory:

1) Quantify error due to p, T, Mach #, pitch angle, laser properties, spectroscopic parameters, calibration system, etc.

2) Determine why there is a slight dependence on [H_2O] at large mixing ratios.

3) Finish ER-2 JLH calibrations, submit final data.

4) Evaluate WB-57 and ER-2 water vapor (13 July 2002 wingtip-to-wingtip intercomparison).

5) Continue laboratory measurements at JPL to confirm those done at Harvard, and under a wider range of conditions.

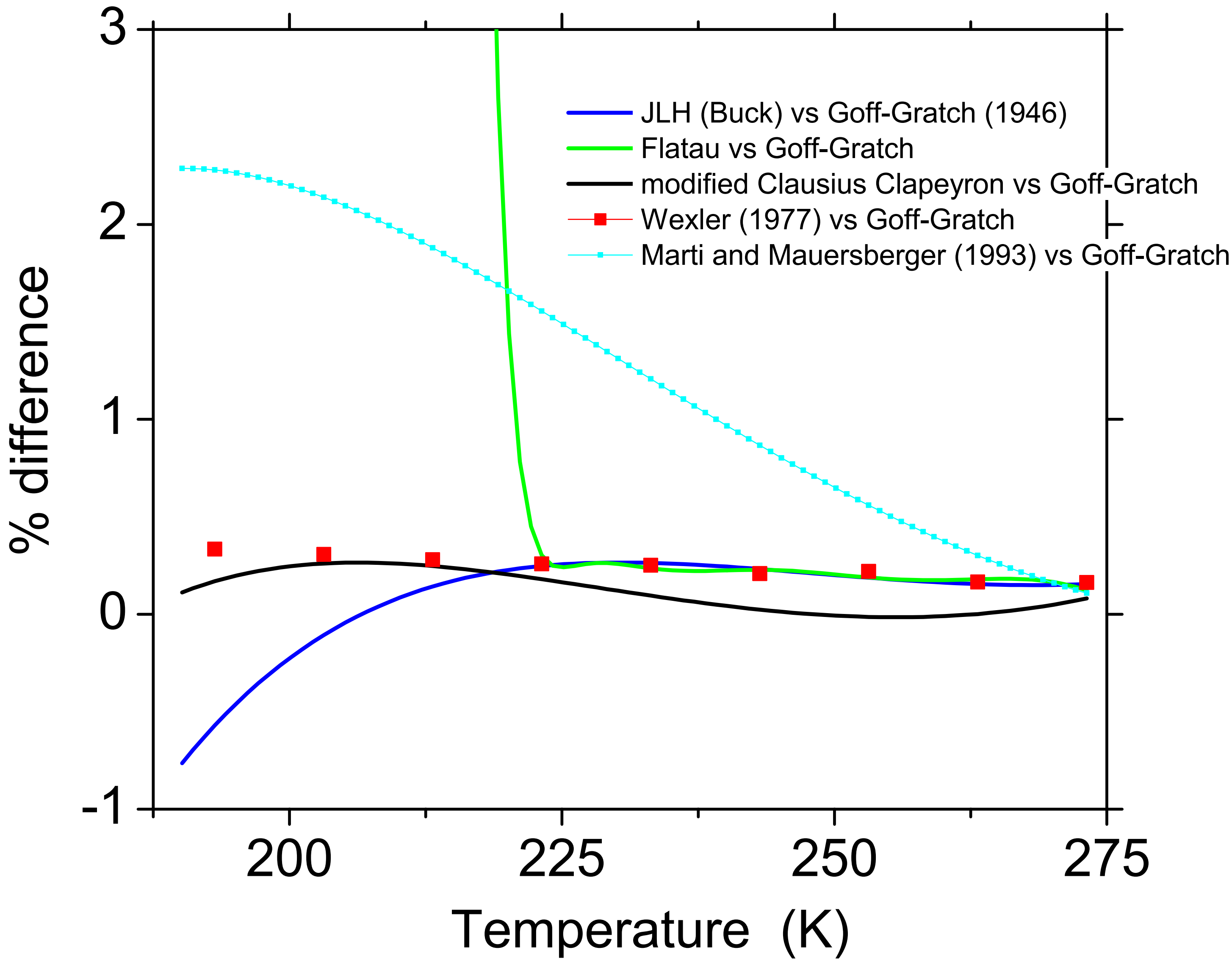
Ongoing Work

Science:

- Continue to model contrail humidity and microphysics.
- Write a paper on contrail studies.
- Examine supersaturations across cloud edges to constrain ice nucleation mechanisms.
- Examine stratospheric water distribution from ER-2 JLH to study transport.

Water Vapor Pressure

H_2O vapor pressure over ice: a comparison



Water Vapor Pressure